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INVESTIGATIONS OF THE NATURE AND BEHAVIOR OF PLASMA DENSITY DISTURBANCES THAT MAY IMPACT GPS AND OTHER TRANSIONOSPHERIC SYSTEMS

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This report summarizes research during the fourth year of a contract for investigating (a) natural variations in ionospheric total electron content (TEC) and (b) plasma and electromagnetic effects produced by transmitting high-powered HF waves into the ionosphere. Ongoing efforts to maintain and utilize data from the Air Force Ionospheric Measuring Systems are being conducted. Initial efforts in upgrading these systems for enhanced data collection and reporting capabilities also are being conducted. Preliminary scintillation capabilities at the GPS L1 and L2 frequencies were established, with additional arrangements for incorporating UHF scintillation measurements also being accomplished. An array of diagnostic instruments is being maintained and enhanced in association with the High-frequency Active Auroral Research Program (HAARP). In addition to a classic riometer and a GPS Total Electron Content (TEC) sensor previously operating at the HAARP site, NWRA also operates a set of Transit receivers for measurements of TEC and scintillation at VHF and UHF, supplementing the receiver at HAARP with a receiver north of the site and an additional receiver installed south of the HAARP site.

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Preface

This report summarizes work completed during the period from 1 September 2000 through 31 August 2001 on a project to investigate effects of the earth's ionosphere on transionospheric systems.

In addition to the authors, other contributors to the efforts described herein were NWRA staff members Angela Andreasen, Charley Andreasen, John Begenisich, Elizabeth Holland, G. Susan Rao, J. Francis Smith, and Tong Xu and NWRA consultants Jens Ostergaard, Sanghun Lee, John Rasmussen, and A. Lee Snyder. We express our appreciation to MSgt. Theodore Denny of the Air Force Research Laboratory at Hanscom for his collaboration in support of the Ionospheric Measuring System (IMS) and the STEL 5010 data recovery; to Randy Hopkins of Raytheon for his on-site support of the IMS at Eareckson Air Force Station, Shemya, Alaska; and to Ian MacGregor and Ally Yates for their on-site support of the RTM at Unst, Shetland Islands.

Acronyms and Initials

55 SWXS	55^{th} Space Weather Squadron
AFRL	Air Force Research Laboratory
AFWA	Air Force Weather Agency
APTI	Advanced Power Technology, Inc.
AWN	Automated Weather Network
BIOS	Basic Input/Output System
CD	Compact Disc
CESR	Contingency Equipment Status Report
CORS	Continuously Operating Reference Station
DCP	Differential Carrier Phase
DGD	Differential Group Delay
DISS	Digital Ionospheric Sounder System
DOP	Dilution of Precision
ELF	Extremely Low Frequency
ESR	Equipment Status Report
FTP	File Transfer Protocol
GB	Giga-bytes (10^9 bytes)
GPS	Global Positioning System
HAARP	High-frequency Active Auroral Research Program
HF	High-frequency
HP	Hewlett Packard
IARC	International Arctic Research Center
IMS	Ionospheric Measuring System
IPP	Ionospheric Penetration Point
ISR	Incoherent Scatter Radar
ITS	Ionospheric Tomography System
MUF	Maximum Usable Frequency
NetCDF	Network Common Data Format
NIMS	Navy Ionospheric Measuring System
NRL	Naval Research Laboratory

NWRA	NorthWest Research Associates
ONR	Office of Naval Research
OpSEND	Operational Space Environment Network Display
PARS	Polar Aeronomy and Radio Science
PRISM	Parameterized Real-time Ionospheric Specification Model
PRN	Pseudo-Random Noise (GPS identification signature)
RAID	Redundant Array of Independent Disks
RINEX	Receiver Independent Exchange (data format)
rms	root mean square
RTM	Real-Time Monitor
SCINDA	Scintillation Decision Aid (system)
SCSI	Small Computer System Interface
SEND	Space Environment Network Display
SFG	Scale Factor Generator
sps	samples per second
SWN	Space Weather Network
TEC	Total Electron Content
TELSI	TEC and Scintillation (message format)
UAF	University of Alaska, Fairbanks
UHF	Ultra-High Frequency
VHF	Very High Frequency
VLF	Very Low Frequency

INVESTIGATIONS OF THE NATURE AND BEHAVIOR OF PLASMA-DENSITY DISTURBANCES THAT MAY IMPACT GPS AND OTHER TRANSIONOSPHERIC SYSTEMS

1. Project Objectives

The ionosphere can both disrupt and enhance the operation of military communication, navigation, and surveillance systems. For instance, the integral of plasma density along ray paths through the ionosphere (the "total electron content," or TEC) imposes range errors on signals received from satellites in the Global Positioning System (GPS). Indeed, GPS transmits two frequencies specifically for the purpose of correcting such errors. The correction depends on reliable measurement of frequency-differential "pseudorange." Such corrections can be applied also to nearby or remote single-frequency receivers, a procedure that can be degraded by temporal changes and spatial gradients in TEC.

An objective of this project is to characterize the temporal changes and gradients in TEC as measured by means of both GPS pseudorange and more precise measurements of frequency-differential carrier phase as the sun advances in its eleven-year activity cycle. To meet this objective, Northwest Research Associates (NWRA) is (a) operating, calibrating, and maintaining GPS-based equipment, including the Air Force Ionospheric Measuring System (IMS, AN/GMQ-35), at various locations and (b) processing and analyzing data obtained thereby. Developments for GPS-related topics are reported in Section II.

It may be possible to enhance operation of some low-data-rate but high-priority communication systems by exercising a degree of control over ionospheric disturbance by means being investigated in the High-frequency Active Auroral Research Program (HAARP). Under HAARP, the Air Force Research Laboratory (AFRL) and the Office of Naval Research (ONR) are developing a facility in Alaska for upper-atmospheric, ionospheric, and solar-terrestrial research. An objective of this project is to contribute to characterizing processes triggered in the upper atmosphere and ionosphere by high-power radio waves transmitted from the HAARP facility, specifically as those processes relate to large-scale and km-scale irregularities in ionospheric plasma density and to radiowave absorption. Developments for HAARP topics took place under this contract during the first quarter of this report period; they are reported in Section III.

2. GPS Topics

2.1 Standard Operations

Data files were processed, reviewed, and archived to tape at each of the deployed IMS sites at Eareckson Air Force Station, Shemya, Alaska; Thule Air Base, Greenland; Croughton Royal Air Force Base, United Kingdom; and Otis Air National Guard Base, Massachusetts. Tapes were catalogued for content and indexed for local storage upon arrival at AFRL each month.

The 15-Minute TEC data from Otis, Croughton, and Shemya were reported by the IMS to AFRL by means of the Space Weather Network (SWN). The data can be plotted for each day to monitor the calibrations, data anomalies, and recent changes in the active GPS constellation. Such monitoring is conducted at a low level of effort following the decision in September 1998 to deactivate the IMS units at Otis, Croughton, and Thule, and the decision in February 2000 to exclude support funding for Ascension Island, which was inactive for most of this report period. The IMS units at Otis and Croughton also have been inactivated, as of February 2001, and both units have been removed from these sites. A quick bias calibration is performed automatically on the Companion PC at the active sites, to facilitate detection of bias variations requiring re-calibration. These calculations are subject to some bias errors due to data anomalies, so operator judgment is required in evaluating the results. Because of IMS data utilization by the COBRA DANE radar at Shemya, a regular schedule of calibrations is performed for that site, so that the IMS is re-calibrated no less often than once every two weeks, and sooner if circumstances or data results indicate a need.

An attempt in March 2001 by AFRL personnel to reinstate operation of the Ascension Island IMS at the site for a campaign was unsuccessful, with an apparent electrical failure for one of the UNIX computers and serious difficulties in starting the other UNIX computer. The UNIX computer with the possible electrical failure was returned to Hanscom for examination, and was found to have a failed power supply, which was replaced.

GPS ephemeris files were retrieved from Holloman AFB on a weekly basis for use in determining the apparent sky positions of GPS satellites and the associated ionospheric penetration-point coordinates, which are used by the bias-determination process.

A summary log was maintained for the Otis IMS, the Croughton IMS, the Thule IMS, and the Shemya IMS, primarily to monitor the duration of operations for each of the two UNIX computer systems in each IMS. The cause of system shutdown also is recorded in this log. A histogram of system operating-time durations, by month, is included in this summary log for each IMS. A summary table displaying the total percentage of operating time for each month and the number of occurrences of various outage causes also has been included.

2.2 Scale Factor Generator (SFG)

The TEC and Scale Factor log files from the Scale Factor Generator (SFG) program at Shemya for the period 30 August 2000 to 4 December 2000 were reviewed. Further review of the TEC and Scale Factor log files from the Scale Factor Generator has not been resumed yet, following the relocation of daily operations from Hanscom Air Force Base, MA to Nashua, NH, in February 2001. Range correction tables were acquired monthly by special arrangements with COBRA DANE personnel. These tables were used to determine the appropriate effective sunspot number for the ionosphere model incorporated into the SFG program. An identical version of the SFG program currently is operating on a computer for the operators there, as well as on the IMS-Net PC. Arrangements were made with the radar operators at Shemya to record scale factors determined from radar measurements into the TEC and Scale Factor log files, and these values also were reviewed. The radar scale factors can be compared directly to the SFG scale factors.

After the failure of the computer at Hanscom that had been used for archiving the SFG data files and logs during the summer of 2000, storage of these files was assigned to another computer at Hanscom. Additionally, the tape archiving process at Shemya was augmented to include these files.

The possibility of generating the radar correction tables by modifying the SFG program was discussed with AFRL personnel, as an alternative to the migration of this capability from 55 SWXS to the Air Force Weather Agency (AFWA), which can generate the table using PRISM instead of the Bent model. Further decisions are required by 55 SWXS and AFWA before any development of this option is commenced.

2.3 Maintenance

The dormant IMS-Net PC at Thule was examined during a field trip in September 2000, to replace a failed tape drive. The Companion PC in operation at Thule was examined to resolve tape drive problems and normal operations were resumed.

The Companion PC formerly in operation at Croughton arrived at Hanscom in autumn 2000, for remediation of the "Year 2000" BIOS problem and further investigation of its FTP server problem. However, the computer casing was seriously damaged in transit, with evidence of some internal damage, so the system was declared unusable. The rack-mountable computers are now available as replacements for the Companion PC, should this become necessary.

In August 2000, electrical maintenance at the laboratory required the shutdown of all of the local computer systems on two successive weekends. Following the second weekend, several systems could not be restarted due to disk drive problems. Among these was the IMS software Development System. A replacement disk drive was obtained for this system, but installation of this disk drive indicated that further components also had failed. A spare Apollo computer was configured with the new disk drive to serve as the IMS Development System in an interim role, until a replacement system can be obtained. Arrangements for transferring the Ada compiler license to this interim Development System were conducted with the vendor. An initial transfer attempt using the HP UNIX version 10.2 operating system for Ada compilations proved unsuccessful, so a revised system configuration using the older HP UNIX version 9.4 was required.

During the summer of 2001, one of the large-capacity server systems previously obtained for evaluation as a possible field site server for the upgraded IMS units was converted for use as a monitoring system for data transmissions from the remote IMS sites, after the failure of the system previously performing this role. Network provisions for this computer also were established. Further developments are required to complete this configuration.

2.4 Software Developments

To overcome the "Year 2000" problems for the GPS survey program previously in use, a program was created to display the number of GPS satellites visible above a specified elevation threshold, using the same azimuth and elevation reference files employed for other applications. An alternative program was created to display the number of satellites actually observed, based on the epoch records in a RINEX file. This alternative program uses the same display format to facilitate comparisons. A significant conclusion derived from preliminary examinations is that up to 14 GPS satellites are visible above the horizon at once for near-polar sites like Thule or

Qaanaaq, and that an elevation threshold of about 12 degrees is needed to insure that no more than 12 satellites (the limit of the Ashtech receiver) are observed at once. This critical threshold corresponds to the limit determined empirically for stable operations of the Thule IMS.

Further provisions were incorporated into the program for plotting sky tracks of GPS satellites, to allow selection of individual satellites and color coding of the satellite tracks.

The program for editing outliers for differential group delay (DGD) values was modified to perform the outlier determination based on data intervals of selectable length, rather than on the entire satellite pass. Further provisions were incorporated to replace edited DGD values with median values for the respective data interval, so that the associated differential carrier phase (DCP) values are retained, rather than eliminating the entire data sample. Retention of the DCP values facilitates the phase discontinuity process that usually follows the outlier editing. This program was tested at Hanscom for calibration processing, and then was installed on the Croughton IMS for further testing. An initial calibration was conducted for the Croughton IMS in December 2000, and the outlier editing process was incorporated into an automated calibration process that evaluated changes in the satellite and receiver biases. The average of the bias changes was monitored over a period of more than two weeks, and a second full calibration was performed for the Croughton IMS. Except for one anomalous evaluation, as illustrated in Figure 1, the automated calibrations reflected the same gradual change observed for the full manually-initiated calibrations, rather than displaying the increased variability previously associated with the occurrence of DGD outliers. This editing process was installed at the remaining field sites for automated processing after the evaluation process was completed.

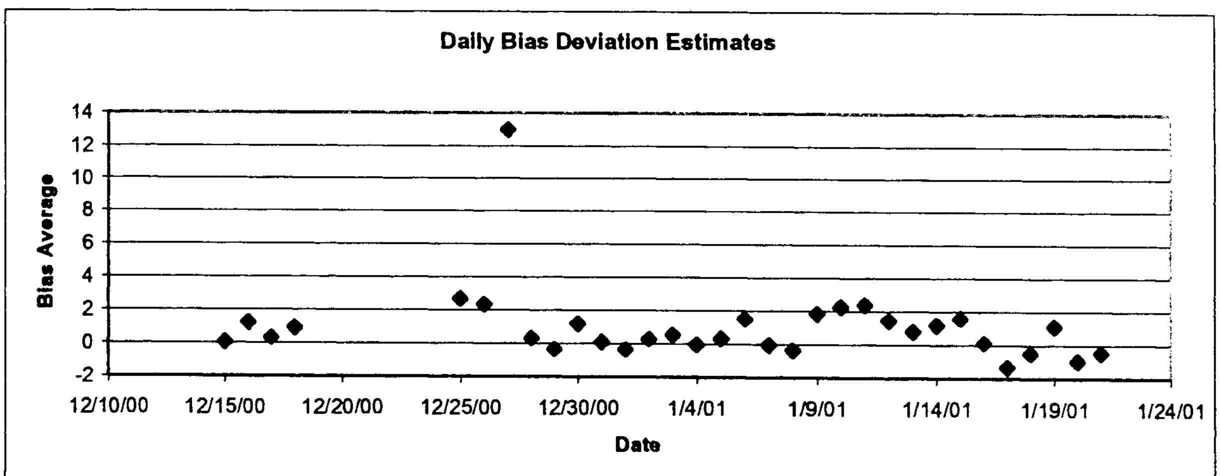

Figure 1. Average of bias deviations from an initial calibration, for the Croughton IMS, after installation of the revised process for editing DGD outliers.

A sample graphics program for plotting tabular files was adapted from the unsupported Microsoft Fortran to the new Compaq Fortran. Other graphics programs for plotting GPS pass files, ionospheric penetration point (IPP) databases, and extended pass files derived from RINEX data also were adapted to the new Fortran.

Discrepancies in some geodetic calculations between the Microsoft Fortran and Compaq Fortran prompted an investigation into the consistency of the trigonometric functions implemented for the two compilers. It was discovered that the Microsoft Fortran is slightly inconsistent for the results of its trigonometric functions and their inverses, while the Compaq Fortran did not exhibit an inconsistency. A larger scope of adapting to the new Compaq Fortran is under consideration, but only based on the consideration of individual cases.

One of the problems encountered previously was the "NO TELSI DATA FOUND" error report, indicating that the summary 15-minute data values for the TELSI message were not available. The UNIX systems did not reset or swap to the alternate system in this circumstance. Modifications were made to the awn_main program and then tested successfully on the HP-UX Visualize system to enable the swap to occur after the "NO TELSI DATA FOUND" detection had been reported for four consecutive quarter-hours.

2.5 Additional Developments

IMS data from the Ascension Island Space Environment Network Display (SEND) campaign of 1999 and the spring 2000 campaign were transcribed to CDs, to facilitate access for development of the preliminary scintillation augmentation of the IMS units.

In autumn 2000, some revisions to the job scheduling process were instituted on the Hanscom system that acquires the 15-minute data transmissions from the IMS sites. Disk drive problems were encountered for this system, and a hard drive was replaced, as well as a removable disk drive. Some problems with the automated FTP retrievals arose subsequently, and the situation was investigated. The job scheduler appeared to stall for unknown reasons, but a method for resolving this condition was determined, although this required manual intervention. The retrievals were discontinued with the apparent hard drive failure of the associated computer on 11 May 2001, after a significant period of declining performance during the previous two months.

The periodic password changes required for access to the AFRL FTP server were accomplished when needed, initially by coordinating with AFRL to institute the change on the local computer while NWRA instituted the changes in all of the fielded systems. NWRA personnel subsequently determined a method for also changing the password on the local FTP server without requiring involvement of AFRL personnel, thus easing the time coordination requirements.

Discussions were conducted with AFWA representatives concerning the contents of the IMS TELSI messages and the associated specifications for the IMS, in connection with the transition of data delivery operations from 55 SWXS to AFWA. Previous material concerning data quality checking implemented at 55 SWXS was reviewed, also in connection with the transition to AFWA. Discussions also were conducted with AFWA representatives concerning the delivery of the IMS TELSI messages to AFWA using the SWN. Provisions were established for independent TELSI transmissions and archiving to redundant AFWA servers, with additional provisions instituted to accommodate the data retrieval and file naming conventions implemented at AFWA.

Support was provided to AFRL personnel with regard to the utilization of the IMS data processing and display procedures, supplementing the written instructions previously provided. Additional batch files were written to expedite the processing and plotting of the IMS scintillation archive files. Modifications were made to the scintillation plotting program to provide flexibility in the scaling and plot formats.

2.6 IMS Modifications

A program of upgrades for the IMS units to implement their specified operational capabilities is in progress. The two major aspects of the upgrades are adaptation and improvement of the communications capabilities to use the Internet-protocol Space Weather Network instead of the modem-based Automated Weather Network (AWN), and incorporation of scintillation measurement capabilities.

During late summer 2000, significant revisions were incorporated into the plan presented at the Preliminary Design Review conducted at Hanscom on 3 August 2000, to accommodate the elimination of the second year of funding. The revised development plan incorporated upgrades only for a prototype system, which was based on the IMS unit then at Otis, and the Shemya system. Development alternatives for the 20-Hz L-band scintillation capabilities also were limited. Because of the sequential nature of many of the developments, the performance schedule was not changed significantly. AFRL personnel provided a presentation based on this plan at a Design Review meeting at Hanscom on 17 November 2000.

In autumn 2000, a more robust computer hardware platform to host the Companion PC operations, for Windows NT, Windows 2000, or Linux, was examined. Two systems containing four 18-GB drives in a RAID configuration and dual Pentium 700 MHz processors were obtained by AFRL in mid-October 2000. One of these systems was provided with replacement disk drives, to preserve the original configuration on the delivered disks, and the replacement drives were configured with Windows 2000. A tape drive was installed to enable the archiving functions of the Companion PC. A Web server was installed on this system to investigate its possible utilization for file access and command implementation.

A pair of rack-mountable computer keyboard and flat-panel monitor units also were delivered to Hanscom in mid-October, and these were installed on the Laboratory Companion PCs for preliminary testing and evaluation.

A provisional development of L-band scintillation statistical parameter tabulations and transmission was completed. These statistical parameters (S_4 and σ_ϕ) were calculated on the Companion PC for one-minute intervals using the 2-Hz amplitude and differential phase data currently reported by the IMS. Associated average and standard deviation values are incorporated into the TELSI message constructed on the Companion PC, for transmission on the Space Weather Network. A separate tabulation of the one-minute statistical parameter values is generated, for use in preliminary evaluations and later diagnostic studies, and the format of this tabulation is indicated in Table 1. A preliminary version of this program was installed on the Otis IMS for evaluation, and automated data collection capabilities for the resulting tabulations were established at Hanscom in December 2000. A subsequent version of the program was later installed on the Thule IMS for testing with different receiver firmware and in more active scintillation conditions. Some differences in the data quality indicators for the two receiver firmware versions necessitated further changes in the scintillation tabulation program. Additional revisions were made to this program to insure that the time in seconds and day of year, specified in the scintillation archive file, refer to the same date. Corrections were made to the array dimensions of the arguments used in the call to the curve-fitting routine used to detrend data for sigma-phi calculations. Data quality indicators were initialized to −1 instead of 0, for better utilization as indicators for missing data. An integer word extension function was used on the signal intensity quantities to insure proper data type conversion, remedying a sign extension problem for the short integer representation. A program for a graphical display of the one-minute values also was developed.

A notable event during the development of the scintillation tabulations was the discovery of time-tag irregularities in the IMS 2-Hz data. These are often just small jitters in an otherwise regular sequence, but occasionally become large enough (greater than one second) to indicate a gap in the data. However, subsequent samples can occur with decreased sampling intervals, so that the net effect is the same as if no gap were present. An algorithm was developed to evaluate the time tags of the 2-Hz data to rectify these spurious time gaps while accommodating true time gaps, and this algorithm was incorporated into the statistical tabulation processing. The source of the time irregularities is believed to be the propagation of timing corrections, obtained from the GPS receiver, through the operating system to the TEC database on the Apollo computers, but investigation of this hypothesis has been postponed until further examination of the IMS Ada code can be accomplished.

Some incompatibilities were encountered while adapting the scintillation tabulation program to the Compaq Fortran, so this adaptation was deferred until the situation with the data quality indicators was resolved. Different versions of the scintillation tabulation program were operating at Otis and Thule to accommodate the different data quality indicators, until the Otis system was removed from operations for upgrading.

Some concerns have arisen with respect to the validity of the signal intensity values used for the intensity scintillation index (S_4), and materials describing these values have been reviewed and compared to descriptions for the 20-Hz intensity values. Preliminary plans for a detailed comparison and validation process have been formulated.

The IMS Ada source code was reviewed for evaluation of extending the data collection capabilities to include 20-Hz Ashtech receiver data, augmenting the status reporting functions to allow network reports, and incorporating additional functionality in setting satellite exclusions.

A preliminary description of the network communications operator interface was developed, assuming that this interface will be primarily using Web pages for information and interactive selections. The cost and schedule estimates associated with this interface mode also were evaluated.

In spring 2001, a major revision of the upgrade plan was developed to accommodate the restoration of funding for upgrades for all five IMS units and the full scintillation capabilities, including scintillation spectral parameters. A critical constraint for this plan was the administrative requirement to deploy the upgraded hardware by the end of the Federal fiscal year 2001 (30 September 2001). Because of the extensive changes required by the upgrade, NWRA proposed that fully equipped IMS upgrade units would be deployed, even if this necessitated some redundancy of individual components for the new units. The operational transition from the original IMS units to the upgraded units at the field sites then could be accomplished with minimal outage duration, and it also would be possible to test the upgraded system by simultaneous operations with the original units at the field sites. Details of this plan were

Table 1. Format of the Scintillation Parameter Tabulation. A single space occurs between each data item. The S_4 and σ_ϕ values are centered on their respective one-minute intervals, with each successive value offset by 30 seconds from the previous value. Missing values are denoted by –1. (Note: For the initial implementation, data files from the IMS are processed individually, so that the initial minute is always incomplete and therefore tagged as a missing value.)

Number of items	Fortran Format	Description
1	I2	Satellite PRN number
1	I4	Year of data
1	I3	Day-of-year of data
1	I5	Starting time of data interval, in Universal Time seconds
1	F5.1	Azimuth for first valid data sample, in degrees (positive clockwise from North, to East; 0 to 360)
1	F4.1	Elevation for first valid data sample, in degrees
1	F5.1	Ionospheric penetration point (IPP) latitude, for first valid data sample, in degrees (positive North)
1	F6.1	IPP longitude, for first valid data sample, in degrees (positive West)
1	F5.2	Maximum S_4 from L1 in this 15-minute interval
1	F5.2	Maximum S_4 from L2 in this 15-minute interval
1	F6.3	Average σ_ϕ, in radians, over this 15-minute interval
30	F5.2	One-minute S_4 values for L1
30	F5.2	One-minute S_4 values for L2
30	F6.3	One-minute σ_ϕ values, in radians

discussed at meetings conducted at the NWRA Nashua office, some of which were attended by AFRL personnel. Among the features of the upgraded IMS units are a dual "front-end" computer configuration, somewhat replicating the dual UNIX computer configuration that has proved advantageous for the current IMS units. The activation of these "front-end" units will be controlled by a small "heartbeat" device. The current heartbeat device for the UNIX computers will be replaced by a smaller network-accessible power controller, with monitoring and control functions being performed by the "front-end" computer, with provisions for operator intervention. A diagram of the proposed configuration, as subsequently revised, appears in Figure 2.

Another feature for the upgraded units is a network mounted hard drive that would replace the SCSI mounted 'data_disk' hard drive that is currently being used. Several scripts have been modified and tested successfully. The Informix database has not been able to be reconstructed successfully on the data_disk, however. This was tried to see if it could be rebuilt after becoming corrupted. More investigations will be needed to resolve this problem.

Possibilities for upgrading the Ada compiler for the IMS software are being considered with the acquisition of new equipment. An Ada compiler that is compatible with the newer HP-UX operating system has been obtained on a trial basis and is being tested for the compatibility of supporting libraries. The HP binding library was missing and has been received from the vendor, Aonix. At least one other library is missing and a possible replacement is being looked for in the new library. Possible upgrades for Informix and Matlab are also under consideration.

In April, NWRA personnel retrieved the Otis IMS and brought it to the Nashua office for upgrading. Due to space restrictions, the antenna mounting had to be removed, but a special tool configuration was required for removal, that was not available at that time. Removal of the antenna was accomplished during a subsequent trip.

The IMS Software Development system has been successfully reconstructed after many different configurations were attempted. Version 5.5.1 of the Alsys Ada is being used, following some difficulties arising from the use of version 5.5.3. Software for the IMS has been recompiled, built, and then successfully tested on the HP Visualize system.

New non-encoded versions of the Equipment Status Report (ESR) and Contingency Equipment Status Report (CESR) messages have been successfully generated as accessible files. A few modifications remain, including decoding the status of each unit being monitored. This will probably be done after the file has been accessed by the operator interface ("front-end") computer. Shutdown situations were emulated and tested for possible CESR conditions.

A draft layout of the network communications operator interface was developed, assuming that this interface will be primarily using Web pages and FTP directories for information and interactive selections. Provisions for transferring status reports from the UNIX data collection systems of the new IMS to the Windows server systems were established, for either ongoing transmission or Web access. A special E-mail account was established at the Nashua office for testing E-mail transmissions of some of these status reports, and a Eudora script was also tested for the possibility of sending the CESR message as an E-mail to an IMS operator.

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In mid-June, a teleconference was conducted by personnel at the NWRA Bellevue and Nashua offices, AFRL, and Scion Associates, concerning options for incorporating the Scion UHF receiver system into the IMS. AFRL personnel expressed a preference for acquiring a Scion unit corresponding to the entire Scintillation Decision Aid (SCINDA) system, with its own operator interface and processing computer and software. Preliminary efforts to arrange the acquisition of these SCINDA units are being conducted by NWRA under a separate contract.

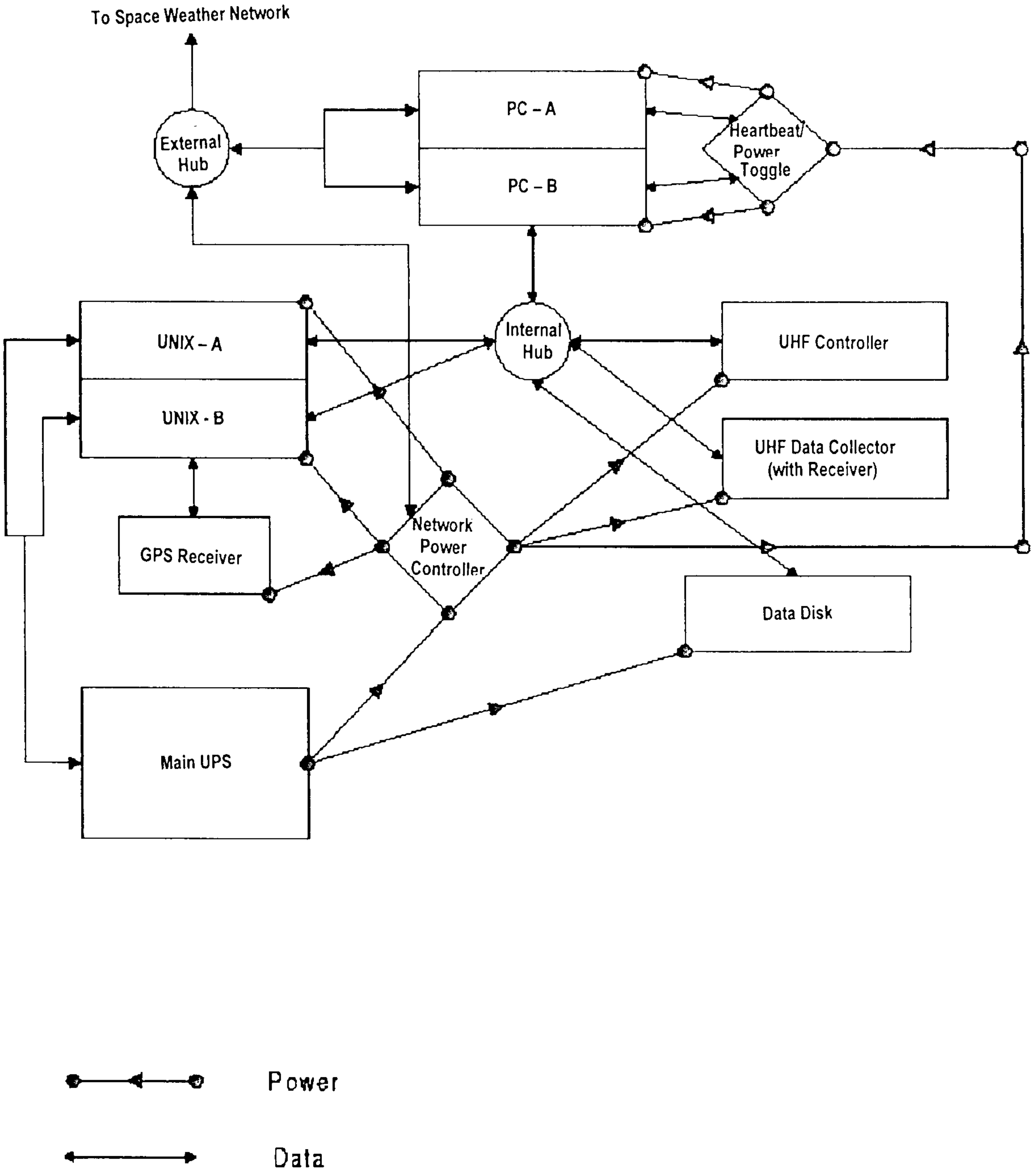


Figure 2. Connectivity diagram for upgraded IMS units, for revised configuration.

2.7 Polar Patch Measurements

A project to study patch regions in the northern polar cap was commenced in autumn 2000. Three GPS receiver systems were deployed to Qaanaaq, Greenland, in early September 2000 to conduct TEC and scintillation measurements, in conjunction with other instrumentation being deployed in the vicinity. The GPS receivers and associated computers were deployed in a small building in the vicinity of the digital ionospheric sounder system (DISS) at Qaanaaq, with the antennas deployed approximately at the vertices of an equilateral triangle, with separations ranging from about 169 meters to about 191 meters.

Documentation for the configuration of the Real-Time Monitor (RTM) data collection on Windows 2000, as implemented for the Qaanaaq systems, was prepared, including provisions for 20-Hz L-band data collection.

Some difficulties in system initialization, data collection, and sustained operations were addressed during the installation and initial period of remote operations, but general performance of the Qaanaaq systems remained erratic, with occasional periods experiencing the loss of 20-Hz L-band data recording while continuing other operations. Diagnostic evaluations and experiments were conducted throughout October 2000, utilizing two different RTM systems at Hanscom (one running Windows 2000, the other running Windows 98) whenever possible. Provisions were incorporated into the process-monitoring applications to verify both the standard TEC data collection process and the 20-Hz data collection process, with actions to restart just the RTM data collection program, or restart the computer, or perform a complete power reset of the receiver and computer, depending upon the circumstances. Data rates for the TEC data collection were decreased and baud rates for the computer serial ports were increased to alleviate anticipated data throughput problems, after examination of satellite coverage histograms. However, attempts to implement an elevation threshold could not be accomplished in a manner consistent with the current system configuration and RTM software. Some tests, employing manual settings, were conducted by personnel at Qaanaaq and at Hanscom. Despite the apparent capability of reducing the number of observed satellites, use of an elevation threshold did not remedy the troublesome operations of the RTM systems. Procedures for excluding individual satellites were developed at Hanscom and subsequently incorporated on the Qaanaaq systems, with some apparent benefit, and a further selection of satellite exclusions was implemented, based on GPS ephemeris calculations and tabulations. Automation of some of the system status reporting was developed to facilitate this selection, but operator-initiated retrievals of this information were still required.

Reliable operations for the RTM data collection were achieved only by reverting to a DOS operating system for the data collection process. This precluded remote monitoring and many automated operations, including archiving data files to tape, but these considerations were not significant for the January 2001 campaign being conducted at Qaanaaq, because manual operations could be conducted by on-site personnel.

2.8 Alternative Data Evaluations

Several RTM systems have been available at Hanscom for development of data collection and processing methods, with particular application to the data-collection systems deployed at the Shetland Islands, HAARP, and Qaanaaq. Various software and script revisions and additions are tested on these systems before use on the deployed field systems. One of these systems, running the RTM program in Windows 98, experienced a hard drive failure during testing associated with the Qaanaaq diagnostic evaluations. It has been replaced by a computer identical to the Qaanaaq computers, and uses Windows 2000.

A Leica receiver acquired by AFRL is being evaluated for future field work for TEC measurements or position determinations. Procedures for initiating automated data collection and partitioning data collection files are being developed.

A meeting was held in early December with AFRL personnel to discuss developments for the processing of data from the STEL 5010 receiver at Thule during the previous solar maximum period (1988-1992). Documentation describing the processing for the STEL 5010 receiver data was revised to reflect some changes in the procedures, and a copy of this documentation was provided to AFRL personnel with a demonstration of the revised procedures.

AFRL personnel were provided with further support to accomplish the processing of data from the STEL 5010 GPS receiver. In addition, supporting software, procedures, and data were migrated to a secondary computer after hardware problems were encountered for the primary processing system. Some problems in the premature termination of processing during scintillation display generation were encountered and were investigated. The Thule STEL 5010 processing documentation was updated to include descriptions of all available batch files for use in processing.

The data from day 22 of 1990 was studied and found to have bad file headers that prevented it from being processed into product files. These data might be salvaged by manually inserting the correct header information.

2.9 GPS Positioning Error Evaluations

A joint effort is in progress for the evaluation of the GPS positioning error maps generated by the Operational Space Environment Network Display (OpSEND) program. Position determinations reported by single-frequency GPS receivers will be compared to their known locations, and the positioning errors will be compared to results derived either from TEC values calculated using PRISM or from TEC values measured directly at the receiver location. NWRA is responsible for recording the single-frequency GPS positions for the receivers located at Hanscom and HAARP (Gakona, AK) and providing the corresponding dual-frequency GPS TEC measurements, while Boston College and AFRL will perform the PRISM evaluations and generate the OpSEND results.

A Trimble Pathfinder single-frequency GPS receiver used for previous campaigns was restored to operational use, together with its associated portable computer and data collection software. It was immediately evident that the Pathfinder or its associated software could not compensate for the GPS Week Rollover, which had occurred on 22 August 1999, because the software was reporting dates in March 1981. Nevertheless, the position determination values appeared reasonable, although further examination of the recorded data is necessary. Information from Trimble indicates that the Pathfinder receiver also could have "Year 2000" problems, so a replacement receiver was sought.

A Trimble GeoExplorer receiver was acquired as an operational successor to the single-frequency Trimble Pathfinder receiver, but the GeoExplorer was inappropriate for the intended application because the separation between the antenna and receiver was restricted. The GeoExplorer was exchanged for a later version of the Trimble Pathfinder, for which the GPS Week Rollover and Year 2000 problems had been resolved, and this Pathfinder was configured with a computer system for single-frequency position data collection at Hanscom.

The AFRL Leica receiver was configured with a computer to support both TEC measurements and dual-frequency position determinations. Procedures for initiating automated data collection and partitioning data collection files were developed, but problems with the sustainment of that process forced the adoption of a continuous data collection mode, with occasional operator intervention to partition the data file.

This Leica receiver was used to evaluate the GPS sky coverage for prospective antenna locations at Hanscom. The primary site, on the penthouse roof of one of the wings of the AFRL building, already provided antenna cable access to internal rooms, with computer equipment available. Examination of the sky coverage, by plotting elevation versus azimuth coordinates for actual GPS measurements, indicated that sky coverage was generally available down to 10 degrees elevation and sometimes lower. Evaluations of multipath for this antenna siting indicated that this was not extreme, so the penthouse site was utilized.

To achieve consistency in GPS satellites tracked between the single-frequency Pathfinder and the dual-frequency Leica, the two receivers were connected to the same Leica antenna, using an amplifier signal splitter. This approach removes geometrical-obstruction effects that could occur if separate antennas were used, and also achieves consistency between multipath effects on the two receivers.

Some software and procedural developments were accomplished to perform these initial investigations, including adaptation of a TEC display program to the reduced variable set but higher data rate of the Leica receiver, and a post-processing display of position determinations by the Leica receiver.

Data collection for the first season of the evaluation was conducted at Hanscom from mid-January to mid-February 2001. Several new procedures were instituted for processing TEC data from the Leica receiver, and some programs were revised to handle the larger volume of data associated with its higher data rate. Initial stages of the data processing were begun.

Cost and schedule estimates were developed for an extension of the validation effort, using an existing dual-frequency GPS receiver at the HAARP site in conjunction with a second new Trimble Pathfinder receiver to be deployed to the HAARP site. Only two seasons of data collection (spring and summer) were included in this extension, to match the overall period of performance for the data collection being conducted at Hanscom. Provisions for utilizing the HAARP Web displays to support data selection for this effort were demonstrated.

Data collection for the spring and summer seasons of the evaluation was conducted at Hanscom Air Force Base, MA, and Gakona, AK, where single-frequency GPS data were collected by a Trimble Pathfinder receiver that was installed in early April. Dual-frequency GPS data are available from the RTM system currently operating at the HAARP site. Both receivers are connected to the same antenna using a signal splitter.

At Hanscom, problems with further data collection were traced to the replacement antenna signal splitter. The Leica antenna takes its power from the Leica receiver and, with the signal splitter interposed, the antenna did not receive sufficient power for operation. To allow data collection to continue, the Trimble Pathfinder and the Leica were each connected to their own antennas, separated by only a few feet. A redesigned signal splitter is planned, where the antenna power is taken directly from the splitter's internal power supply, making operation of the receivers independent.

A meeting was conducted at AFRL in mid-May to discuss the deliverable data items required from NWRA, for both the single-frequency and dual-frequency GPS receivers. The following items were agreed upon:

- Text tabulations of single-frequency positions (latitude, longitude, altitude) versus time
- Plot files in commonly used format for latitude/longitude/altitude versus time (2, 3, 4, or 6 plots per day, to achieve adequate resolution)
- Processing tools on shareable media
- Text tabulations of dual-frequency (calibrated) slant TEC versus time
- Plot files for vertical TEC versus IPP local time.

Batch files were written to plot data for this project. Data from the dual frequency Leica receiver are displayed as satellite pass files of equivalent vertical TEC and satellite azimuth and elevation, versus universal time. The single-frequency Trimble receiver data are shown as latitude, longitude, and altitude versus time. These plots will be used to survey a month of data so that specific days of interest for further analysis can be identified.

Software for the Trimble Pathfinder receivers was examined to determine the appropriate technique for acquiring the parameters of interest from the recorded data. Some change in the format of the binary data for the new Pathfinder receiver appears to have eliminated access to the identification of the GPS satellites actually used for the position determination. Newer software was obtained from Trimble to produce the satellite identifications, with information that all visible satellites are used for the position determination, rather than only those four providing the best dilution of precision (DOP). Software was developed to reformat the data from the Trimble program into the required tabulation of position estimates, position error, and satellites. An Excel spreadsheet with supplementary macros was developed to acquire and plot these tabulations in the desired format, generating two plots per day, each of twelve hours duration. A sample plot set for the first half 23 April 2001 for data acquired at Hanscom is displayed in Figure 3.

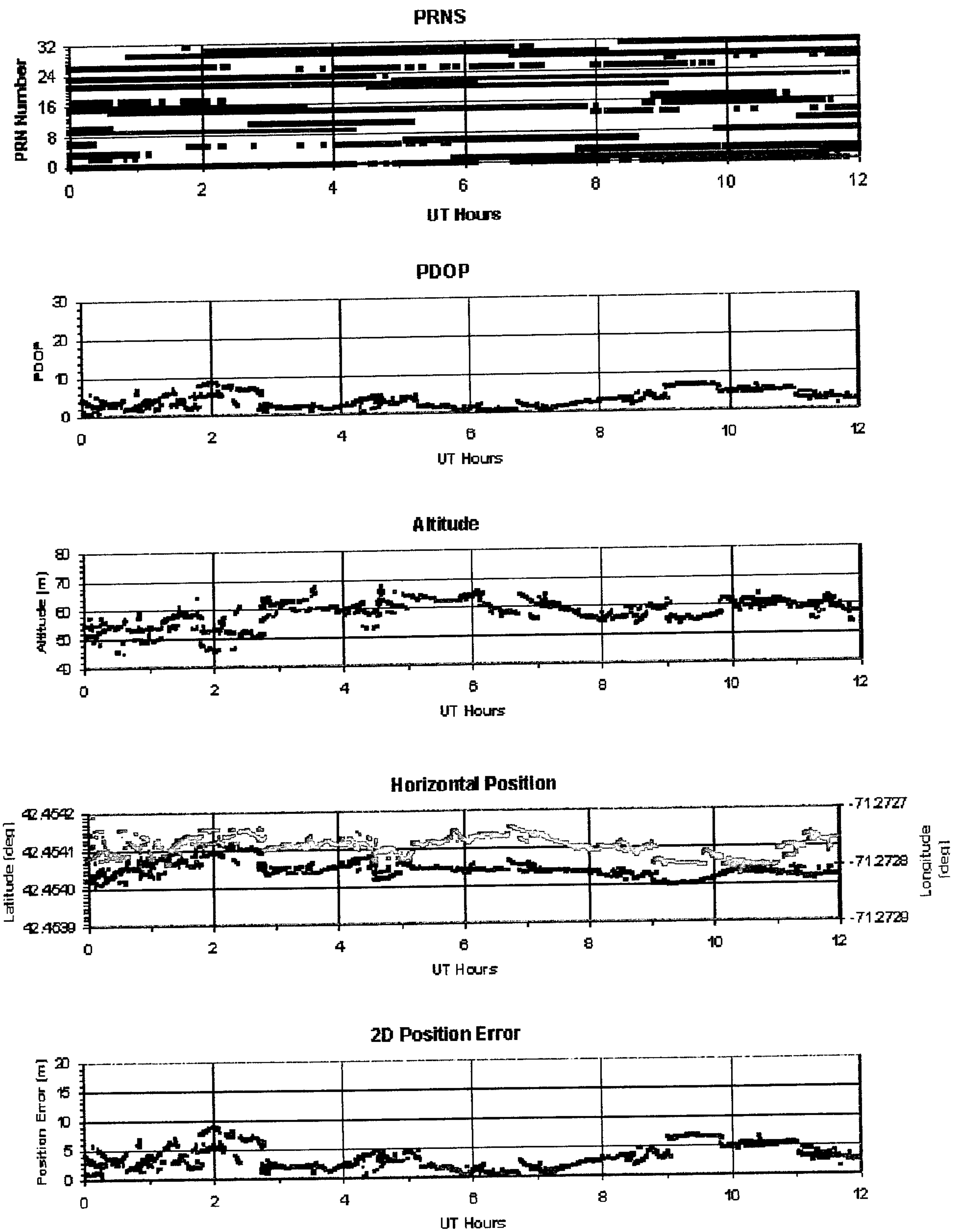
2.10 International Collaborations

An RTM data-collection system continued operations at Unst, in the Shetland Islands, with occasional dial-up connections from AFRL. Archived data, received on tape at Hanscom, are being processed for calibrated TEC diurnal variations.

Joint meetings with researchers from the Defence Evaluation and Research Agency of the United Kingdom were held at AFRL at Hanscom on 3 October 2000. Selected segments of TEC data from Unst were processed, for display by AFRL personnel.

A software upgrade for the TEC calibration processing to overcome GPS Week Rollover and Year 2000 problems was requested by collaborating researchers at the University of Wales at Aberystwyth. The appropriate software components were identified and delivered.

Figure 3. Sample set of plots for position determinations using Trimble PathFinder GPS receiver.



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3. HAARP Topics

Under HAARP, an observatory is being constructed in Gakona, AK, to conduct upper-atmospheric, ionospheric, and radio-propagation research. In addition to a high-power HF transmitter being installed by Advanced Power Technologies, Inc. (APTI), NWRA is facilitating installation of an array of geophysical diagnostic instruments. During this report period, NWRA's HAARP activities involved several of these diagnostics, as well as coordination with other researchers, with APTI, and with the interested general public, as described in the following subsections.

3.1 Classic Riometer

Early in this report period, the classic 30-MHz riometer operating at Gakona developed a problem of signal loss in its antenna-feed system. NWRA Consultant Jens Ostergaard initiated diagnostic efforts, with assistance from Consultant John Rasmussen and from Dr. Helio Zwi, of APTI. Toward the end of isolating the source of loss, the instrument was operated for a time with each individual antenna element connected directly to the receiver sequentially. Subsequently, the problem was traced to a faulty balun in one of the eight Yagi antennas employed. The balun was replaced, and the antenna array now is fully functional.

The riometer also experienced an increase in propagated interference under current (solar-maximum) ionospheric conditions, in which the maximum useable frequency (MUF) often is at or slightly above 30 MHz. With propagated interference being a common problem for riometry, several remedies have been devised. The most obvious is use of a frequency consistently higher than the MUF on possible propagation paths, but frequency extrapolation is problematic at high latitudes due to the patchiness of absorption. A preferred approach would be to employ an IF bandwidth substantially narrower than that used in the HAARP riometer (200 kHz), together with a frequency sweep and minimum-strength detector. Such modification was beyond the scope of this contract, and a new riometer is being developed under separate contract. Meanwhile, the operating frequency of the existing riometer was shifted to a relatively "clean" portion of the band, and its bandwidth was narrowed to 30 kHz. These steps have reduced the effect of propagated interference substantially.

3.2 GPS Receiver for Measuring Absolute TEC

An Ashtech Z-FX Continuously Operating Reference Station (CORS), consisting of a 12-channel GPS receiver and a choke-ring antenna, currently is in service at HAARP, with data collection being performed by the RTM program. Under this contract, the data-collection procedure was supplemented by a real-time process to convert one-minute reports from the RTM program into "ionospheric penetration-point (IPP)" databases, which become the source of calibrated measurements of absolute TEC to be displayed on the HAARP web site.

Ionosonde data processed by the Center for Atmospheric Research at the University of Massachusetts at Lowell are reported on the HAARP web site and contain derived values of vertical-TEC. Since early December 1999, daily summaries of these derived vertical-TEC values have been retrieved from the HAARP web site for comparison to GPS vertical-TEC measurements, using GPS TEC measurements performed at elevations greater than 65 degrees.

Additional quantitative comparisons are performed for days on which HAARP GPS calibrations are conducted. A discrepancy between the two measurements, reported previously, still exists.

On the RTM computer, a number of the intermittent one-minute processing operations were found halted by an untraceable error and awaiting operator intervention to be terminated. An automated method for detecting and correcting this condition was sought, but without any successful conclusion.

High speed winds toppled the GPS antenna structure at the site in August 2000, and the antenna structure was re-erected and fastened more securely. Subsequent examinations of the multipath patterns indicated that the possible damage to the antenna cable from this incident was minimal, and further examination was conducted during a site visit by NWRA consultant John Rasmussen. No identifiable problems were discovered by visual examination or electronic testing of the antenna cable, but the bias values have been considerably more stable since this visit, and the data-collection performance appears to be somewhat better, although long outages still have occurred, requiring remedy by a remote operator. Some design features of the Heartbeat Re-booter in use with the RTM computer system may account for failure of an automatic restart in these circumstances, and acquisition of an updated unit was considered. This upgrade, together with a replacement RTM computer, was acquired and deployed under a separate contract.

3.3 GPS Determinations for Position

Program development for using GPS pseudorange measurements to calculate position estimates were completed, a software review was conducted, and preliminary test cases were studied. Different results for position determinations were obtained for different compiler settings and also for different Fortran compilers. The source of the discrepancies eventually was determined to be differences in the results of trigonometric functions. These findings have resulted in corrections that will be employed with the Trimble Pathfinder receiver referred to in Section II I to display, under a separate contract, single-frequency GPS position estimates on the HAARP Web site.

3.4 Transit Receivers for Recording Latitude Scans of Relative TEC

An NWRA ITS10S coherent radio receiving system is operating at Gakona to record differential (dispersive) phase between the mutually coherent VHF and UHF signals transmitted from Transit satellites in the Navy Ionospheric Monitoring System (NIMS). The differential phase recorded at 50 samples per sec (sps) during passes of approximately 15 minutes duration provides latitudinal scans of relative TEC over Alaska, smoothed to one sps and referenced to the minimum value recorded during the pass. A second ITS10S receiver has been operating near Delta Junction since September 1999, and a replacement ITS10S was installed there during the site visit in May 2000.

Early in this reporting period, NWRA Engineer J. Francis Smith installed a third ITS10S, to the south of Gakona. In preparation for that installation, at Cordova, we tested several candidate antenna configurations at a general-aviation airport near Arlington, WA, a small town somewhat to the north of Bellevue. The tests were conducted throughout September and October and until 17 November of 2000, so that each of the antenna configurations could be employed during several passes of each of the nine satellites employed for observations at Delta and Gakona.

Doing so permitted definitive assessment of the utility of each of the satellites, in addition to that of each antenna configuration. Based on these tests, we chose a turnstyle over a ground screen for use at all sites.

The 50-sps data rate of the ITS10S receivers provides a capability for recording radiowave scintillation, given sufficient signal strength to obviate the need for smoothing. As deployed for HAARP, the receivers are outfitted with very simple, fixed antennas (as described in the preceding paragraph) directed toward the zenith. Even with such low-gain receiving antennas, the signals received from the Transit satellites and some other Transit-like satellites are sufficiently strong to record scintillation during at least high-elevation portions of their passes (typically above 20 deg or so for the Transits). Accordingly, we implemented recording of dispersive-phase scintillation at both Gakona and Delta during this report period.

An example of a combined TEC and phase-scintillation record posted on the HAARP web site is shown in Figure 4, along with the pass geometry. The lower strip in the upper panel displays 50-sps phase residuals obtained after detrending by subtraction of the output from a low-pass filter having a sharp cutoff at 0.1 Hz (i.e., after removal of trends with periods greater than ten sec). The residual trace is displayed when the average signal-to-noise ratio over a running ten-sec window exceeds 14 dB on both VHF and UHF. As a quantitative measure of scintillation, the rms value of phase fluctuation also is calculated during ten-second periods in which at least 250 acceptable residual values are recorded. The results are included at the end of ASCII and netCDF files posted on the HAARP web site.

The data illustrated in Figure 4 are from a pass of a Transit satellite that occurred near the end of a period of geomagnetic activity. It revealed scintillation-producing irregularities even to the south of Gakona. The scintillation enhancement that occurred just after five minutes from the pass start, as the line of sight scanned near Gakona's magnetic zenith, is a geometrical effect due to field-alignment of the irregularities.

Conversion from relative slant-path to absolute vertical-TEC may be performed most reliably by integrating vertically through tomographic images of plasma density. Given a sequence of such measurements from a single station, an approximate conversion can be made under sufficiently simple ionospheric conditions. Such approximate conversion relies on an ad hoc assumption, usually that of a slab-like ionosphere devoid of horizontal gradients. Even with such an ad hoc assumption, one needs additional information to account for the unknown offset inherent in records of relative TEC (stemming from the $n\pi$ ambiguity in the dispersive phase actually measured). We have implemented a hybrid method of calibrating Transit passes for different sites against each other and against GPS TEC measurements as a means of deriving such information.

Developments for an automated implementation of the hybrid method on the RTM system at Gakona were completed and documented, but the provisions to eliminate "orphan" cases, in which the ITS10S measurements did not satisfy conditions to allow a valid calibration, experienced erratic performance. The source of the problem could not be isolated, and post-processing simulations of failed cases did not replicate the phenomenon. Consequently, the ITS10S calibration processing was halted until an alternative process could be implemented.

In the alternative process, the derived bias values are applied directly to the TEC files produced by the ITS10S system, rather than translating TEC values derived from the ITS10S IPP databases. The elimination of the "orphan" cases can be performed directly by examination of the associated bias values, and the appropriate designations can be applied for the Web displays. The inclusion of Cordova as a source of ITS10S data also was implemented with the processing revisions.

3.5 Spaced Receivers for Scintillation Measurements

Under a separate contract from AFRL, Scion Associates has installed a spaced array of antennas and associated receiving equipment for recording signals from slow-moving satellites (near their apogee in highly eccentric orbits). Scintillation analysis of the received signals is expected to yield information on the structure (spatial spectrum) and motion of km-scale plasma-density irregularities produced by HAARP heating and by natural causes. John Rasmussen coordinated efforts to achieve real-time transfer of these data to the HAARP Operations Center and to integrate them onto the HAARP web site.

3.6 Coherent Backscatter Radar

HAARP has acquired a 139-MHz radar for measuring coherent backscatter from fine-scale ionospheric irregularities. During this report period, Mr. Rasmussen coordinated construction, by Ahtna Construction, of the support structure for the radar's antenna array, including installation of 80 Phillystran guy lines to tension the structure.

3.7 Optical Instruments

Consideration is being given to adding a lidar facility to the HAARP diagnostics suite. John Rasmussen coordinated establishment of a working group to plan the facility. The group is charged with determining HAARP's long- and short-term lidar requirements and recommending an implementation approach. Mr. Rasmussen also coordinated improvement of the infrastructure employed by optical imagers and the archiving of data from them.

3.8 Scientific Collaboration on and Coordination of Diagnostics

Under auspices of HAARP, a Student/Faculty Science Campaign was conducted in August 2000. During that campaign, Prof. Roger Smith, of the University of Alaska Fairbanks (UAF), and Dr. John Foster, of Haystack Observatory, Massachusetts Institute of Technology, queried members of the HAARP team on the concept of distributing the three faces envisioned for an incoherent-scatter radar (ISR) in the National Science Foundation (NSF) Relocatable Atmospheric Observatory. From those discussions emerged an approach of locating one of the faces at HAARP.

Drs. Foster and Smith related the foregoing approach to NSF, suggesting that more science issues could be explored with the distributed ISR resources than by concentrating them. NSF acknowledged this grassroots suggestion and approved further exploration within the community involved with Coupling of Energetics and Dynamics of Atmospheric Regions (NSF's CEDAR program). During this period, Dr. Snyder has coordinated meetings of interested parties to discuss the distributed approach, including location of a face at HAARP.

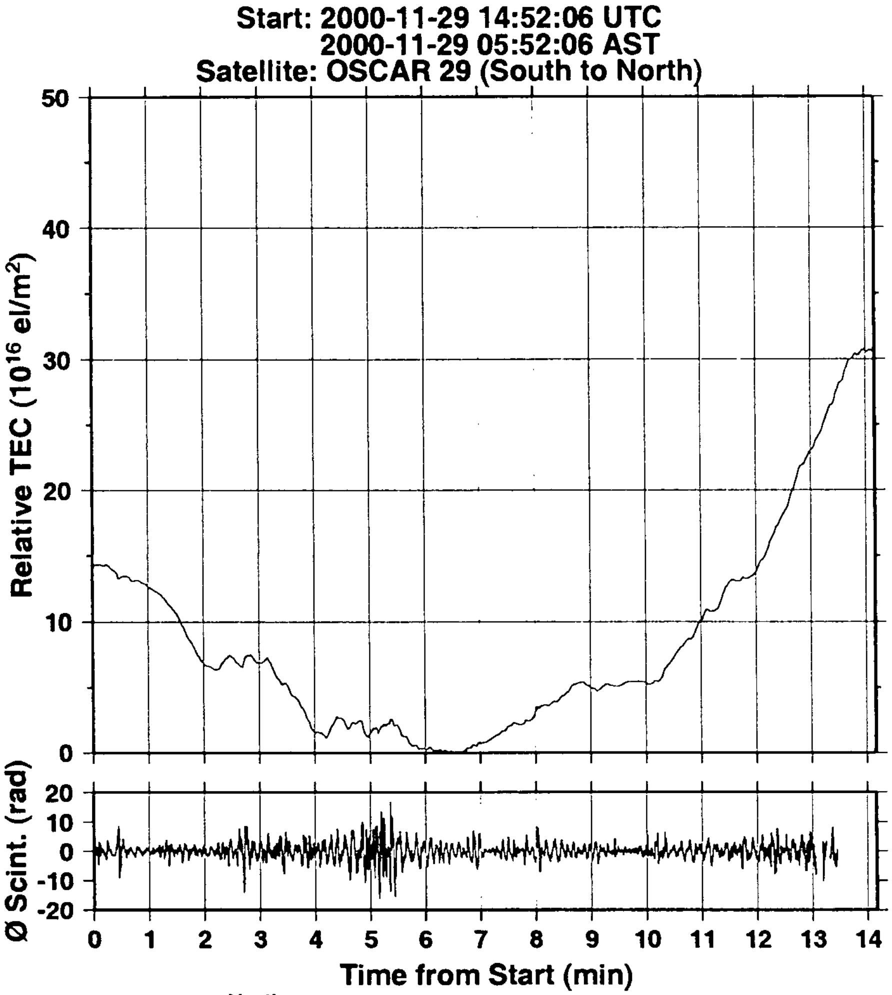
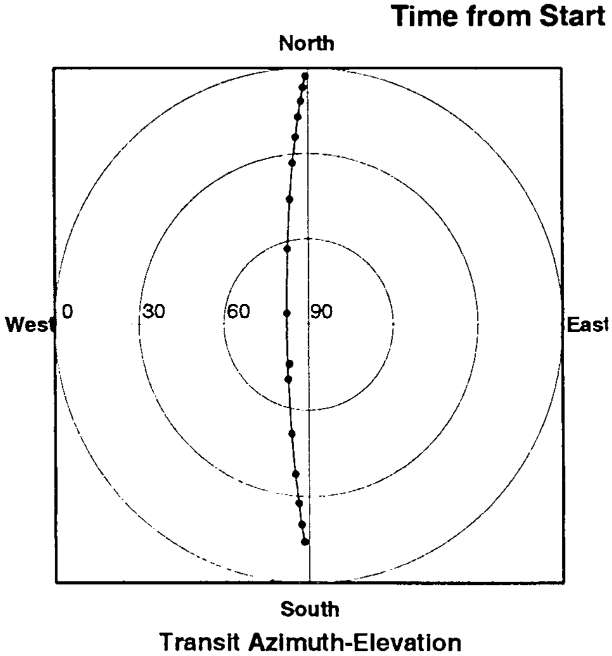
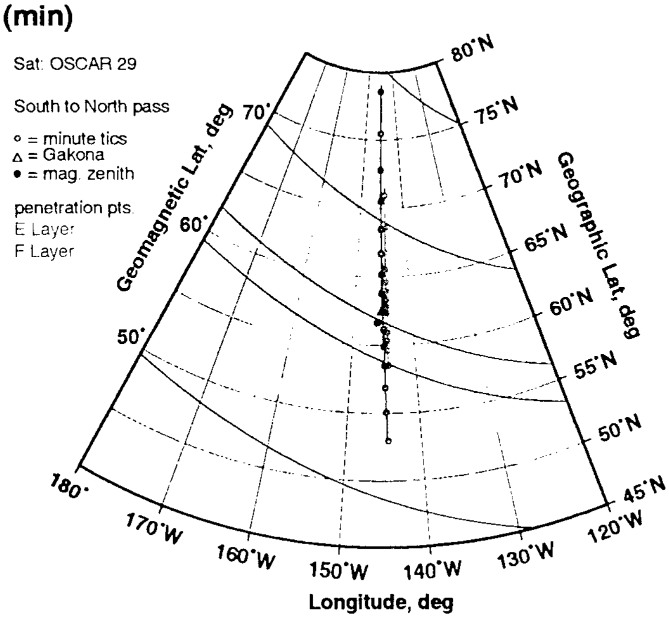


Figure 4. Example of HAARP web display showing dispersive-phase scintillation, along with relative TEC, during pass of a Transit satellite over Gakona (geometry below).





3.9 Broader Scientific and Educational Collaboration

NWRA Consultant Sanghum Lee extended a linear analysis by Consultant Spencer Kuo and other collaborating HAARP researchers into the non-linear regime via a numerical study of ELF/VLF generation by modulation of the auroral electrojet via an X-mode HF heating wave. Earlier results indicated that ELF radiation intensity (at 100 Hz) increases abruptly when the power of the heating wave exceeds a critical level, p_c. During the first quarter of this report period, Mr. Lee established that p_c increases with the frequency of modulation. He then proceeded to investigate the non-linear damping rate as a function of electron temperature in an effort to understand the physical mechanism for the abrupt increase. Initial results of that investigation indicate that the damping rate increases with electron temperature in a low-temperature regime, peaks, and then drops suddenly.

A Student/Faculty Science Campaign was conducted in August 2000. During the first quarter of this report period, Dr. Snyder coordinated receipt of experiment summaries from each student/faculty team and prepared a Campaign final report based thereon. The report was submitted to AFRL and NRL on 15 November 2000. A copy was provided also to the Campaign Executive Agent, the University of Alaska Fairbanks (UAF).

As related in R&D Status Report 12, a new International Arctic Research Center (IARC) has been established at UAF. During that report period, Dr. Snyder held discussions with Professors S.-I. Akasofu and Joseph R. Kan aimed at establishing a relationship between HAARP and the new Center. Those discussions included development of a proposed research program to develop multi-disciplinary teams of scientists to undertake polar aeronomy and radio science (PARS) projects that exceed the capability and/or resources of any one participating research organization. Early in this report period, the PARS proposal was submitted to the Office of Naval Research (ONR) for evaluation. On 6 October, ONR awarded a two-year grant to IARC to initiate PARS activities. The first project constituted a follow-on to the Summer 2000 Student/Faculty initiative; in the second, NWRA Sr. Research Scientist Edward Fremouw organized and conducted a science workshop regarding multi-longitudinal tomographic imaging of the high-latitude ionosphere; and the third will focus the interests of several groups in ULF/ELF/VLF magnetospheric probing experiments.

3.10 Diagnostic Infrastructure

John Rasmussen facilitated planning for expansion of site roads and pads to meet demands for additional instrumentation space. During this report period, work was initiated to extend the road one-half mile and to provide two additional instrument pads for HAARP diagnostics, as well as other facilities.

Several problems in the new Operations Center identified during the preceding contract year were resolved satisfactorily this year, including mitigation of intruding diesel fumes associated with operation of the diesel-electric generator. Along with the move to the new Operations Center, an effort was undertaken to turn in trailers used for the old operations facility. A decision has been made that, since these trailers were acquired by APTI for temporary use, have served their intended purpose, and aren't worth further investment for needed repairs, the contractor may dispose of them.

In addition to the aforementioned consolidation, a general cleanup of the HAARP site was undertaken. As part of this effort, Dr. Snyder coordinated with Mr. Gene Laycock, of AFRL, to arrange removal and turn-in of 380 pounds of Freon, a hazardous chemical that had to be disposed of in an officially approved manner. Such turn-in was arranged with and completed through Elemendorf AFB, AK.

3.11 Other HAARP Planning and Coordination

In Annual Report No. 3, we related plans for transfer of an AN/TPS-63 radar from the U.S. Marine Corps to HAARP for use as an aircraft alert radar. During this report period, Dr. Snyder continued to serve as a member of the integrated product team for the radar. Both he and Mr. Rasmussen participated in a variety of planning and coordination meetings, at several of which Mr. Rasmussen represented HAARP diagnostic interests.